(1) TITLE

RE-USABLE MANDREL FOR FABRICATION OF INK-JET ORIFICE PLATES

(2) CROSS-REFERENCE TO RELATED APPLICATIONS

None.

(3) STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

None.

(4) REFERENCE TO AN APPENDIX

None.

(5) BACKGROUND OF THE INVENTION

(5.1) FIELD OF THE INVENTION

[0001] The present invention relates generally to ink-jet printhead fabrication and, more specifically to making a re-usable mandrel to electroform orifice sheets with a defined, tapered profile.

(5.2) DESCRIPTION OF RELATED ART

[0002] The art of ink-jet technology is relatively well developed. Commercial products such as computer printers, graphics plotters, copiers, and facsimile machines employ ink-jet technology for producing hard copy. The basics of this technology are disclosed, for example, in various articles in the *Hewlett-Packard Journal*, Vol. 36, No. 5 (May 1985), Vol. 39, No. 4 (August 1988), Vol. 39, No. 5 (October 1988), Vol. 43, No. 4 (August 1992), Vol. 43, No. 6 (December 1992) and Vol. 45, No.1 (February 1994) editions. Ink-jet devices are also described by W.J. Lloyd and H.T. Taub in *Output Hardcopy [sic] Devices*, chapter 13 (Ed. R.C. Durbeck and S. Sherr, Academic Press, San Diego, 1988). Also, many publications describe the details of common techniques used in the fabrication of thin film devices and integrated circuits that can be generally

employed in the fabrication of complex, three-dimensional, silicon wafer substrate structures; *see e.g., Silicon Processes*, Vol. 1-3, copyright 1995, Lattice Press, Lattice Semiconductor Corporation (assignee herein), Hillsboro, Oregon. Moreover, the individual steps of such a process can be performed using commercially available fabrication machines. The use of such machines and common fabrication step techniques will be referred to hereinafter as simply: "in a known manner." As specifically helpful to an understanding of the present invention, approximate technical data are disclosed herein based upon current technology; future developments in this art may call for appropriate adjustments as would be apparent to one skilled in the art.

[0003] The state of the art is continually developing to improve the quality of the fundamental dot matrix form of printing intrinsic to ink-jet technology. Current products have achieved print densities of 1200 dots-per-inch ("DPI"), achieving print quality comparable to the more expensive laser printers. To that end, thin-film technology has been employed to produce precision components such as orifice plates, fine mesh ink filters, and the like, for ink-jet printheads.

[0004] For example, ink-jet pens can utilize an orifice plate generally formed on a thin-film mandrel. The mandrel can consist of a glass plate coated with a conductive film. Non-conductive discs are defined on the surface of the conductive film for determining the location and size of the orifices. Generally, the discs are about three times the diameter of the target hole size. Looking to FIGURE 1 (Prior Art), the profile of an electroformed ink-jet nozzle is described by a relationship between the exit bore diameter, D_{bore}, the mandrel pad (non-conducting region) diameter, D_{pad}, and the thickness, T, of the electroformed sheet:

$$D_{bore} = D_{pad} - 2T \qquad \text{Equation 1.}$$

The orifice size is determined by carefully controlling the electroplating parameters (current, timing, and the like) for forming an orifice plate on the mandrel. Therefore, a variation in these parameters will directly affect the size of the orifices. Moreover, if a thicker orifice plate is needed, it is necessary to increase the disc size. Manufacturing tolerances limit such disc dimensioning, resulting in a decreased orifice diameter if the thickness of the orifice plate increases over the disc size tolerance.

[0005] One example of an improved METHOD OF MAKING INK-JET COMPONENTS is described in U.S. Patent No. 5,560,837, Oct. 1, 1996, by Trueba (assigned to the common assignee herein and incorporated herein by reference). Trueba shows a process for fabricating a thin-film structure using a transparent substrate. A first structure, such as a ring having a central pillar, is formed of a conductive material on a surface of the substrate. A photoresist material pillar is formed on top of the conductive material central pillar by exposure through the transparent material.

[0006] Generally, state of the art orifice plating mandrel is two-dimensional, meaning that the profile of the orifice assumes a curved shape while the electro-deposited material grows. This is disadvantageous because the ink drop exit bore diameter depends directly on the plating thickness as a function of position. As a result, the bore diameter standard deviation is large across an orifice sheet.

[0007] As the state of the art progresses, ink-jet orifice bore diameter tends to decrease. Bore diameter standard deviation for tolerance needs to be reduced. Moreover, bore profiles need to be more accurately engineered so that pen performance can be optimized.

(6) BRIEF SUMMARY OF THE INVENTION

[0008] In its basic aspect, the present invention provides a process for fabricating a mandrel including: forming a first structure having a substantially planar electrically conductive surface having a plurality of electrically non-conductive mandrel associated first features affixed distributively across said conductive surface; using said first structure, forming a complementary second structure such that said complementary second structure has a plurality of second features complementary of said first features; and

using said second structure, forming the mandrel having third features wherein said third features define shape, location and geometry of features of an electroform created using said mandrel.

[0009] In another aspect, the present invention provides a process for fabricating an ink-jet printhead mandrel including: forming a first structure having a substantially planar metalized first surface having a plurality of dielectric first features distributed across said first surface; using said first structure, forming a complementary second structure such that said complementary second structure has a plurality of second features complementary of said first features; and using said second structure, forming the mandrel having third features wherein said third features define shape, location and geometry of features of an ink-jet printhead to be electroformed using said mandrel.

[0010] In still another aspect, the present invention provides an ink-jet printhead mandrel including: a glass substrate having a plurality of glass-formed mandrel features for electroforming an ink-jet printhead construction hereon; a metal layer superjacent the glass substrate conforming to said features; and a dielectric layer superjacent the metal layer only on and conforming to said features.

[0011] The foregoing summary is not intended to be an inclusive list of all the aspects, objects, advantages, and features of the present invention nor should any limitation on the scope of the invention be implied therefrom. This Summary is provided in accordance with the mandate of 37 C.F.R. 1.73 and M.P.E.P. 608.01(d) merely to apprise the public, and more especially those interested in the particular art to which the invention relates, of the nature of the invention in order to be of assistance in aiding ready understanding of the patent in future searches. Objects, features and advantages of the present invention will become apparent upon consideration of the following explanation and the accompanying drawings, in which like reference designations represent like features throughout the drawings.

(7) BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIGURE 1 (Prior Art) is a schematic depiction of a known manner electroform.

[0013] FIGURES 2A through 2F are sequential, schematic, cross-sectional views depicting the process in accordance with the present invention.

[0014] FIGURES 3A and 3B demonstrate an alternative embodiment of steps of the process as shown in FIGURES 2A-2B.

[0015] FIGURE 4 is a depiction of a mandrel in accordance with the present invention as shown in FIGURES 2A-2F (wherein "D_{bore}" corresponds to the diameter of the feature at the thickness of the electroform growing around the feature).

[0016] FIGURE 5 illustrates the electroforming of the metal nozzle plate sheet 500 using the mandrel as shown in FIGURE 4.

[0017] The drawings referred to in this specification should be understood as not being drawn to scale except if specifically annotated.

(8) DETAILED DESCRIPTION OF THE INVENTION

[0018] Reference is made now in detail to a specific embodiment of the present invention, which illustrates the best mode presently contemplated by the inventors for practicing the invention. Alternative embodiments are also briefly described as applicable. It should be understood that the drawings herein represent one small cross-section of a larger structure having a plurality of the exhibited features. Ink-jet printhead nozzle plates are fabricated in electroformed sheets from which individual nozzle plates are scribed and separated; a typical sheet measures approximately 6 inches-by-6 inches. For example, each nozzle plate may have an array of hundreds of nozzles in columns where the nozzles have an orifice target diameter of 0.0006 inch, separated from each other by 1/300th inch.

[0019] Turning now to FIGURES 2A-2F, a method is described for fabricating mandrels with raised features associated ink-jet printhead nozzle plate manufacture in accordance with the present invention. Forming a final raised feature(s) associated with the ink-jet nozzle plate on a glass substrate is accomplished by making two "parent" mandrels, a "father" mandrel and a "mother" mandrel. The final mandrel used in electroforming nozzle plate sheets will be referred to as the "child" mandrel.

[0020] Beginning with the father mandrel process, starting with a planar glass substrate 201 (commercially available from Hoya Corp. USA of San Jose, CA), a superjacent metal 203 layer (e.g., preferably stainless steel such as SS316L or a like characteristic metal) is formed via known deposition manner. Note that this step may include incorporating another intermediary layer, such as chromium, so that the stainless steel will have a better adherence. The metal 203 layer has a thickness, "T," in the range of approximately 0.5 to 1.0 µm. A superjacent photo-imagable polymer

205 is spun in a known manner onto the metal 203 layer. A commercial negative photoresist, such as SU8[tm] from MicroChem Corp. of Newton, MA, can be employed; commonly called a "negative resist" as unexposed regions are stripped in subsequent steps. The thickness of the negative resist 205 is controlled through the spinning process and should be at least as thick as the desired thickness of the orifice plate sheet.

[0021] Turning to FIGURE 2B, the negative resist 205 is masked 207 in accordance with the pattern of features to be formed and exposed to light (generally ultraviolet, UV; represented by descending arrows). The exposed region is depicted with the speckled shading. As is known in photolithography arts, the exposure results are controlled by the thickness, the intensity of the light, and the distance between the mask and photoresist. Thus, the exposure steps can be tailored and optimized to a specific implementation. The photoresist is cured in a known manner.

[0022] As illustrated by FIGURE 2C, the unexposed portions of resist 205 are stripped from the metal 203 layer surface 203', leaving a resultant father mandrel 211: a metalized glass substrate with an array of pillars 209 of cured polymer, the pillars having a defined position and shape, namely the inverse shape of the nozzles to be formed in an orifice plate with the spacing and position defined by the specification of the specific orifice plate(s) to be formed. (Note that a positive resist can be used reversely, viz., with a reversed mask, stripping away the exposed resist to leave the same structure, father mandrel 211 of FIGURE 2C.)

[0023] Starting now with the father mandrel 211 of FIGURE 2C, the next part of the process is to electroform the mother mandrel. Illustrated by FIGURE 2D, the mother mandrel made by electroforming a metal (e.g., nickel) sheet 213 over the father

mandrel 211 to a height "H" that is greater than the thickness of the pillar(s) 209 protruding above the father mandrel surface 203'; i.e., H>T. The electroformed metal sheet 213 is removed from the father mandrel 211. Note that the photoresist pillar(s) 209 have formed complementary depression 217 features as shown in FIGURE 2E. The electroformed metal sheet 213 can be then mounted to a substrate 215 for added strength and rigidity.

[0024] The next part of the process is to make the child mandrel which is ultimately used for fabricating the target ink-jet orifice plates. Turning to FIGURE 2F, starting with the mother mandrel 221, a superjacent layer of glass 223 is formed by melting glass over the mother mandrel. The glass will flow into the depression 217 features of the mother mandrel 221. Note, using a vacuum oven to heat the glass - mother mandrel sandwich to a liquify the glass is advantageous as it removes gasses from the depression(s) 217, minimizing any pitting (air bubbles) in the flowed glass. Alternatively, melting glass beads that pour into the depression 217 features may also be employed to this advantage. Next, mother and child are separated; the taper of the depression 217 features and the low adhesion of nickel to glass facilitates the separation of the backed metal 213 mother mandrel 221 from the all glass child mandrel piece 223.

[0025] Turning to FIGURE 4, it can now be recognized that a solid glass child mandrel 401 piece has been formed. The top surface 401' is metalized, preferably with stainless steel in a known manner as with metal 203, FIGURE 2A et seq., to a thickness in the approximate range of 0.5 to 1.0 µm, forming a superjacent metal 403 conformed to the shape and dimensions of the solid glass child mandrel 401 piece's top surface 401' features. Again, using a photoresist masking process, child mandrel

pillar(s) 405 are rendered non-conducting by depositing a dielectric, preferably silicon carbide, "SiC," to a thickness in the approximate range of 3500 to 4000Å. The child mandrel 411 is completed, ready for use in electroforming orifice plate sheets for ink-jet printheads. Thus, FIGURE 4 shows a child mandrel 411 in accordance with the present invention having physical features 405 to control the ink-jet nozzle bore profile. Each physical feature has the inverse shape of the desired bore geometry. For example, the feature(s) 405 can have a circular base with a truncated conical shape having a taper angle Θ. The relationship between the electroform thickness, base diameter, and nozzle exit bore is now in accordance with the equation:

$$D_{bore} = D_{base} - 2T\tan\Theta \qquad \text{Equation 2.}$$

[0026] FIGURE 5 illustrates the electroforming of the metal nozzle plate sheet 500 using the child mandrel 411. Because of the structure of the child mandrel 411 fabricated in accordance with the present invention, the mandrel is reusable, providing significantly better control over the shape, dimensions, and relative spacing of the nozzles.

[0027] An alternative embodiment for forming a father mandrel is illustrated in FIGURES 3A-3B. In effect, it is an inverse process to FIGURES 2A-2C. As depicted by FIGURE 3A, a positive photoresist 207' is exposed; in FIGURE 3B, the exposed resist is stripped leaving a mother mandrel 311 having a resist 205 having an array of "pot holes"309 associated with the nozzle(s) shape and dimension, again represented as "D_{bore}." (Note here that a negative resist can be used reversely, viz., with a reversed mask, stripping away the unexposed resist to leave the same structure.) However, this embodiment is more difficult to use in forming the mother mandrel, primarily because it is difficult to remove exposed resist in the recess of an acute angle of a feature having

a small size.

[0028] The foregoing description of the preferred embodiment of the present invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form or to exemplary embodiments disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. Similarly, any process steps described might be interchangeable with other steps in order to achieve the same result. The embodiment was chosen and described in order to best explain the principles of the invention and its best mode practical application, thereby to enable others skilled in the art to understand the invention for various embodiments and with various modifications as are suited to the particular use or implementation contemplated. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents. Reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather means "one or more." Moreover, no element, component, nor method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the following claims. No claim element herein is to be construed under the provisions of 35 U.S.C. Sec. 112, sixth paragraph, unless the element is expressly recited using the phrase "means for. . ." and no process step herein is to be construed under those provisions unless the step or steps are expressly recited using the phrase "comprising the step(s) of. . .." What is claimed is: